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# FUTURE OF EARTH ORIENTATION PREDICTIONS

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**ABSTRACT.** Earth orientation prediction has undergone a number of changes over the last few decades in response to changing conditions in the Earth orientation parameter user community. However, considering the recent pace of change, it is likely that the rate at which innovations are introduced into the prediction process will increase. Potential drivers for change are discussed and possible directions for change are outlined.

**Keywords:** Future Earth Orientation Parameter Predictions

## 1. INTRODUCTION

The prediction of Earth orientation parameters (EOPs) has been an ongoing task since 1979. The last three decades have seen significant, but mostly evolutionary, changes to the prediction process. Different prediction algorithms have been tested and the more promising have been adapted to operational use. Additional parameters such as the celestial pole offsets $d\psi/d\epsilon$ and dX/dY are now being predicted. Data files are provided electronically through a variety of means such as web files, ftp and e-mail. Even the frequency of predictions is increasing as data latency has been reduced. However, all of these have been natural progressions; straightforward responses to improvements in the observations made in an attempt to anticipate (or at least catch up to) needs of the operational and scientific users. Now, with the pace of technological change quickening, it becomes more important to gain the appropriate perspective on several critical facets of the prediction problem such as user needs, data availability, and technical advancements.

## 2. USER NEEDS

While there are many interesting academic aspects to the determination and prediction of EOPs, they also meet a more practical need. EOPs are used in such wide-ranging fields as navigation, pointing, real-time orbit determination, ephemerides, and leap second determinations. With the variety of uses for EOPs and in order to provide the most suitable products, it is necessary to understand the needs of the EOP user community. The current EOP needs for pointing, ephemerides, and leap seconds appear to be met with the current level of accuracy. More accurate EOP predictions are needed for real-time Earth satellite orbit determination and VLBI analysis. Since tasks such as real time orbits can have such wide-ranging and beneficial impacts on monitoring precipitable water

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vapor, tsunamis, and earthquakes, it is likely that the need for improved access to better estimates and predictions of EOPs will only grow in time.

In order to meet the needs of the EOP user community, it is important to define in specific terms what those needs are. Ideally this should be a part of an ongoing dialog, but realistically speaking, it is something that can only be determined through intermittent inquiries, such as through surveys. In 2006–2007 such a survey of the EOP user community was performed and it showed that an increasing number of users are interested in shorter-term predictions. These are appealing because they are generated in near real time, reducing the latency between observation and prediction, and thereby increasing the forecast accuracy.

Another thing that will potentially change the way EOP predictions are used is the possibility that leap seconds will be eliminated at some point in the future. The International Telecommunications Union (ITU) is considering the possibility that leap seconds be eliminated by the end of the next decade. If leap seconds were eliminated, a new category of EOP prediction users would be created that would need UT1-UTC predictions to replace their use of UTC as a proxy for UT1. Attempts should be made now to understand how this change could impact the future delivery of EOP predictions.

## 3. PREDICTION DIRECTIONS

The following is an attempt to speculate on the directions that the EOP prediction process is likely to follow. These predictions about predictions are based on current understanding of EOP users needs, educated guesses in changing technology, all while being mindful of the need to provide information in a user-friendly manner.

*Need for improved EOP nowcasting*

The best way to minimize the error in EOP prediction is to reduce the time between the epoch of an observation and its prediction. The logical extension of this is to provide EOP nowcasting, i.e. very short-term EOP predictions. While this will have an impact on all EOPs available for real time use, its impact will not be identical for all EOPs. For instance, since UT1-UTC varies the most rapidly, it would be expected that "nowcasts" of UT1-UTC would reduce the total error due to Earth orientation the most. Similarly, polar motion and celestial pole offset errors would also be expected to decrease, but to a lesser extent.

In comparison to EOP nowcasting, the need for improvements in long-term predictions is secondary. Long-term predictions are typically used for the calculation of ephemerides and determining the need for leap seconds. The current long-term EOP prediction capability appears to be adequate for these purposes.

*Need for improved near-real-time data*

In order to maximize the benefits of EOP nowcasting, the near-real-time data that are used as input to the process should be as "good" as possible. This requires data with the best accuracy and the least latency. While the need for improved accuracy is self-evident, it is likely that the greatest impact would be from reducing the latency of the data. There are several existing (e.g. IGS Ultra-rapid prodcuts) or planned (eVLBI) data sets that should provide the low latency data needed for EOP predictions in the future.

*Need for improved automation*

It is unrealistic to expect that the turnaround time needed for EOP nowcasting and near-real-time EOP observations will be available without reliable, well-designed automated processes producing and checking the results. Practically speaking, this means that the scripting used to generate the results will need to be more sophisticated with an

emphasis on the ability to self-correct. One of the biggest impediments in this process may be that past processes have been designed with human intervention in mind. In the future, it is likely that human intervention will be minimized further. Therefore the sophisticated scripting and self-correcting ability should be written is such a way as to optimize the information flow from computer program/script to computer program/script. This will almost certainly need to be done at the cost of de-emphasizing the flow of information from computer to human.

*Need for improved modeling*

Improvements in real-time data will also require improvements in the associated analysis modeling. Particular emphasis should be devoted to high frequency variations such as diurnal and semidiurnal tidal models. While improvements in longer-term effects will improve the general results, it is expected that they would not have as significant an impact on the short-term predictions, which are expected to be emphasized more heavily in the future.

*Need for improved geophysical forecasting*

As the relationship between geophysical forcing and EOP continues to be better understood the use of geophysical forecasts will play an even more significant role in the future than it does today. The quality of geophysical forecasts will benefit from current research into improved modeling particularly for atmospheric angular momentum (AAM) and oceanic angular momentum (OAM). In addition, hydrologic angular momentum (HAM) estimates and consistent AAM+OAM+HAM series could prove to be beneficial.

Something that is not currently being investigated is suitable operational metrics for the determination of the quality of geophysical forecasts. Quality indications could be used to weight the forecasts appropriately in order to optimize the results. This is an area that needs more attention.

*Need for improved real-time prediction procedures*

Producing real-time predictions is not just a matter of running a program more frequently. The entire process of assembling input data, checking for possible errors, running the combination and/or prediction algorithms, and disseminating information depends on the required forecast frequency. This could vary from continuous updates to a once-per-day output. This philosophy should be an integral part of the design of real-time predictions. Note, however, that improvements in design will only be a part of the solution. With the generation of real-time operational software, it will likely be necessary to adopt more stringent coding procedures to facilitate the operations under the much more stressful situation of nearly continuous operations.

In an effort to provide near-real-time information, the IERS Rapid Service/Prediction Center (RS/PC) will transition to more frequent updates of its solutions. Twice per day updates are expected by the end of 2010 with the possibility of increasing the solution frequency to four times per day sometime in 2011. Eventually, the IERS RS/PC anticipates providing continuous EOP updates.

*Need for improved real-time dissemination*

Producing data in near real time is a significant challenge, but it is not the only challenge to creating a real-time data service. Disseminating near-real-time information can be difficult as well, and requires a different viewpoint from disseminating information on a discrete basis. Improvements in machine-to-machine (M2M) communication will probably become the primary focus while machine-to-human communication will become a secondary concern. Investigation into optimal ways to disseminate EOPs should be considered, and the possibility of creating an international standard for EOP dissemination

may become necessary.

*Need for better diagnostic information*

Assuming that real-time EOP computation and dissemination become a reality, the associated diagnostic information will become even more important than it is today. With solutions running faster than individuals can keep up with, the diagnostic information will provide the only way to know when manual intervention might be needed. This significant responsibility needs to be reflected in the design of the diagnostic software and resulting information. Some of the characteristics of the diagnostic procedures should concentrate on including more complete information, more understandable diagnostics to external users, and greater flexibility to accommodate wide-ranging circumstances. In addition, it will also be likely that the capability to target the dissemination of diagnostic information will be much more important rather than the common, passive approach to the generation of diagnostic information that exists today.

*Need for better prediction quality indicators*

In conjunction with better diagnostic information, there will be an additional need to provide simplified summary information to both the users and producers of the EOP products. Since automated processing can produce unexpected and possibly even undesirable results, it will be necessary to provide unequivocal status indicators. This could be as simple as the concept of a green light to indicate that the current solutions should be treated as "good" while a red light might indicate a "poor" solution. These status indicators will be needed in order to simplify the quality estimates of an increasingly complicated procedure that will be used by a growing number of non-expert users.

*Need for better communication with input providers and prediction users*

The concept of better diagnostics and status indicators could be summarized within the generic concept of better communication. However, in addition to these two ideas, there will also be a need for improved general communication between input providers and prediction generators and between prediction generators and prediction users. Small, unexpected changes to the operations can have significant impact on the downstream operations, and automated procedures cannot be expected to be sufficiently robust to catch all of these problems. The best method to ensure smooth operations when procedures inevitably need to be modified is to follow well-established use of communications to guarantee that important information regarding changes is provided to the appropriate users in a timely fashion.

*Need for redundant prediction operations*

An additional item that will become more critical with real-time operations is the need for a hot backup production facility. If the need for EOPs becomes nearly continuous, then access to EOPs should also be continuous. This will need to be the case in spite of local computer problems, internet connectivity issues or other localized problems. The backup facility should provide the same support as the primary facility (i.e. same bandwidth, reliable backup power, etc.). There will also need to be well-established, well-tested, and well-publicized procedures to transfer between the primary and the backup facility.

## 4. CONCLUSIONS

As the pace of technological advancement and sophistication continues to increase, the speed of change associated with the combination, prediction and dissemination of the EOPs will also increase. Efforts now to prepare for these changes will allow the EOP user community to transition smoothly from the current state of the art to future conditions.

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